

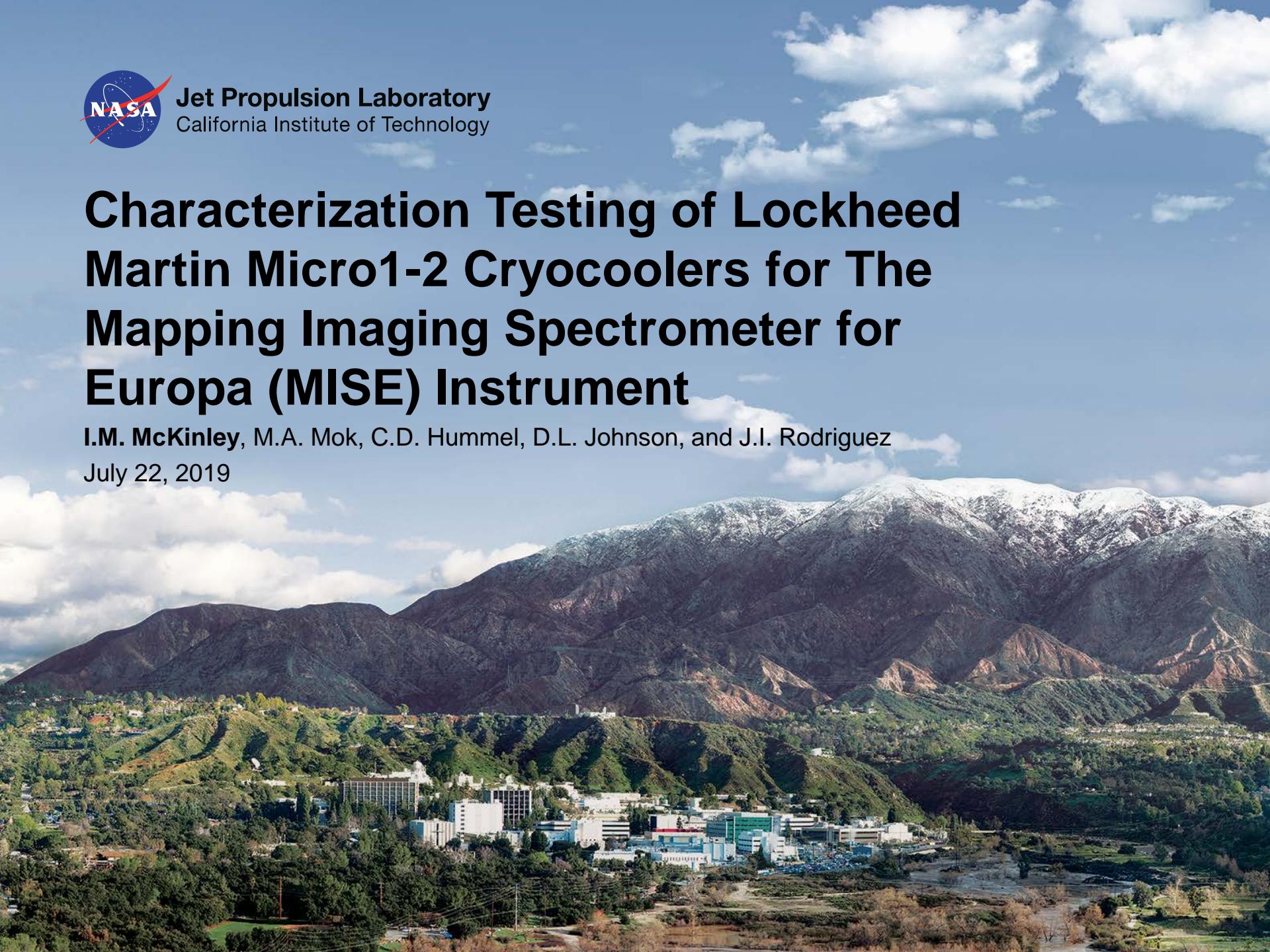


**Jet Propulsion Laboratory**  
California Institute of Technology

# **Characterization Testing of Lockheed Martin Micro1-2 Cryocoolers for The Mapping Imaging Spectrometer for Europa (MISE) Instrument**

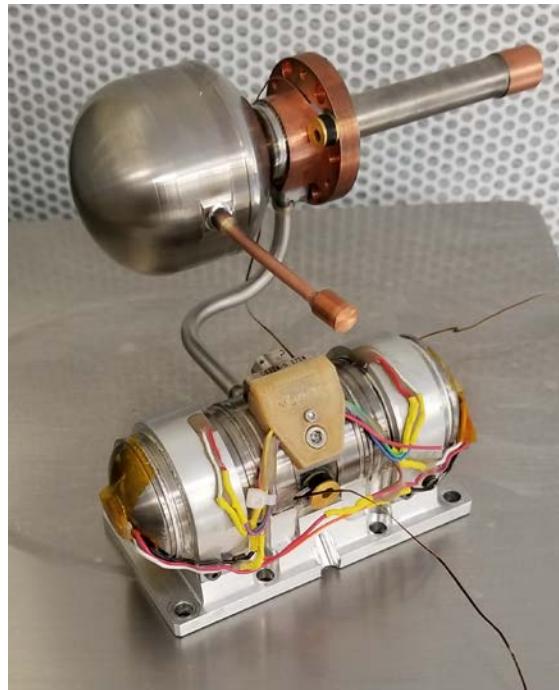
I.M. McKinley, M.A. Mok, C.D. Hummel, D.L. Johnson, and J.I. Rodriguez

July 22, 2019



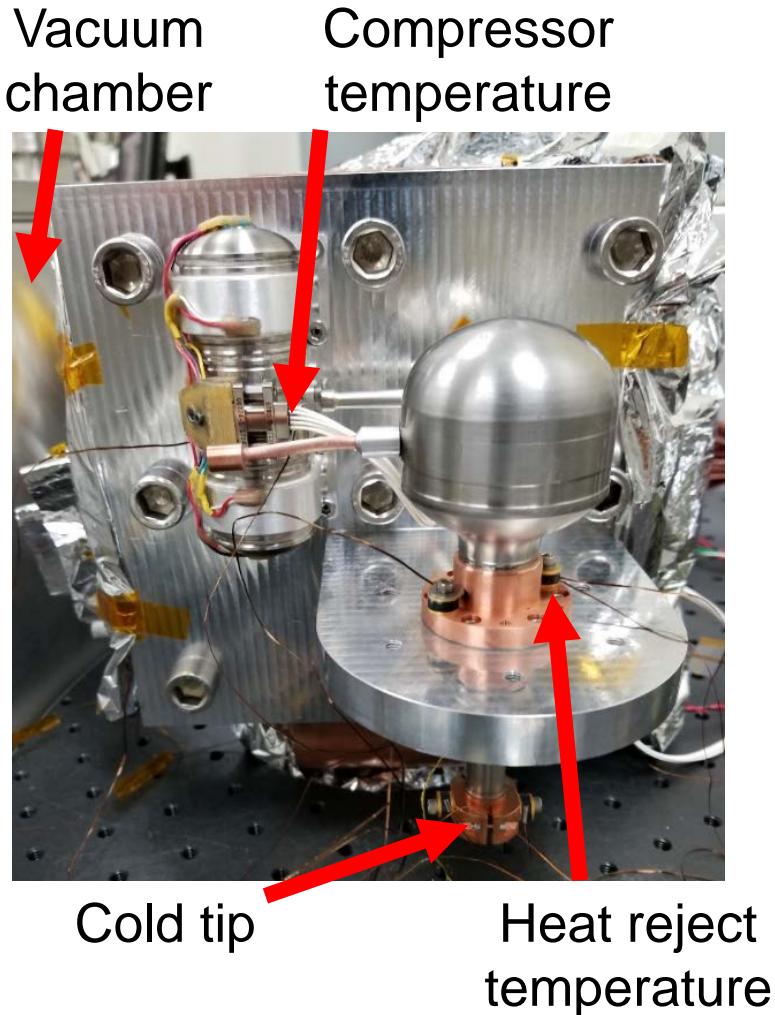
# Lockheed Martin Micro1-2 MISE Prototype Cryocooler

- The Jet Propulsion Laboratory procured two prototypes for the Mapping Imaging Spectrometer for Europa (MISE) Instrument on the Europa Clipper
- Characterization tests were performed to assess the cooler's compatibility with the environmental requirements of the Europa Clipper as well as assess its performance in the expected thermal environment



- Pulse tube type
- Flexure bearings
- Maturity level: TRL 6 for Earth and Europa
- Mass: 480 grams
- Compressor: 92 mm long
- Ti cold finger: 160 mm long
- 60 W maximum input power
- 600 psi to 800 psi He fill pressure
- Optimized for:
  - 80 K cold tip
  - 135 Hz drive frequency
  - 220 K heat rejection temperature

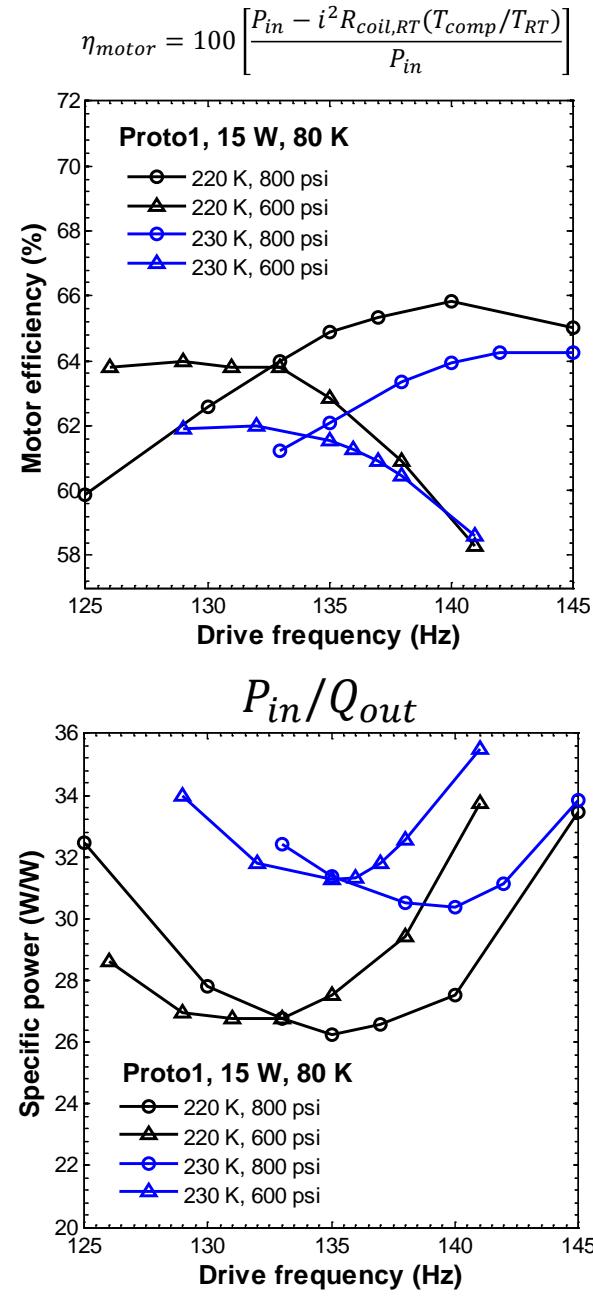
# Thermal Vacuum Performance Testing



- Parametric study:
  - Frequency: 125 Hz to 150 Hz
  - Heat rejection temperature: 170 K to 260 K
  - Input power: 5 to 40 W
  - Heat lift: 0 W to 5 W
- Not shown:
  - Cold tip: MLI
  - MLI surrounding cooler
- Nominally compressor temperature was <5 K higher than expander temperature
- Cooler driven with Chroma 61602 AC power supply

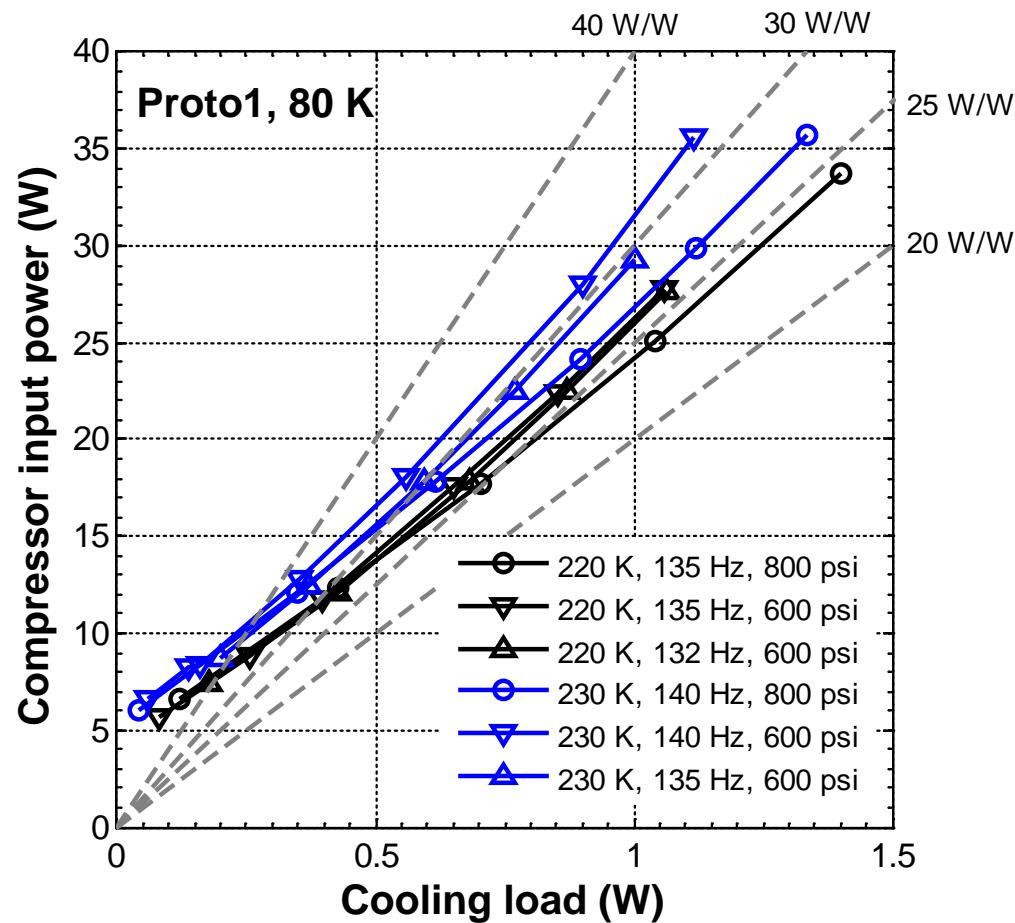
# Effect of Fill Pressure

- Input power fixed at 15 W
- Cold tip fixed at 80 K
- Two different expander temperatures and helium fill pressures
- Lowering fill pressure
  - Decreased the optimal drive frequency
  - Decreased the motor efficiency
  - Increased the specific power



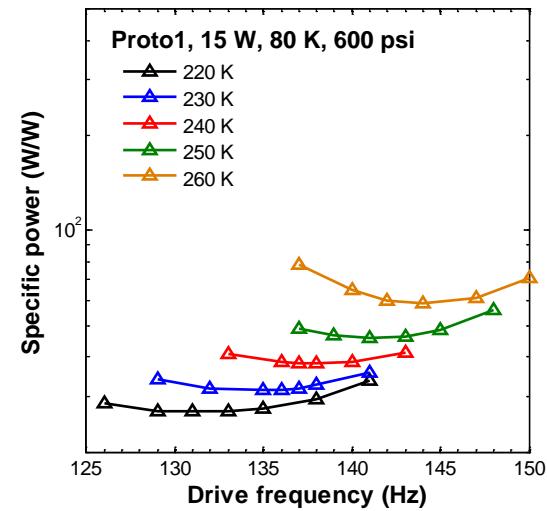
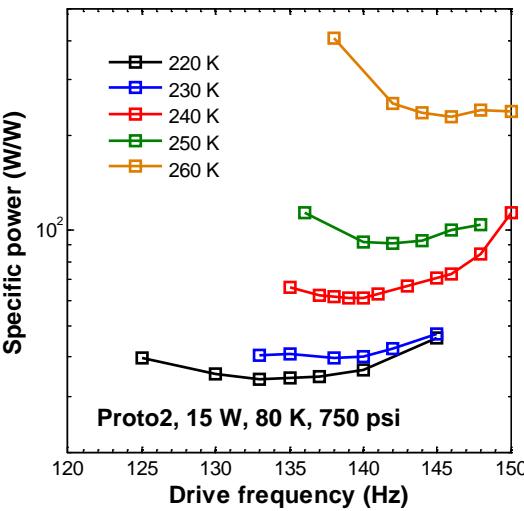
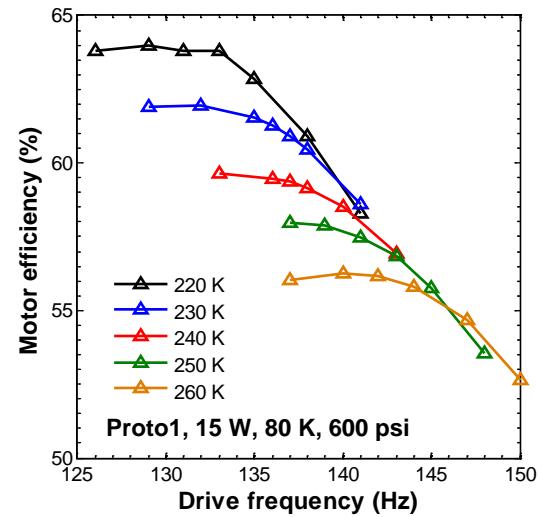
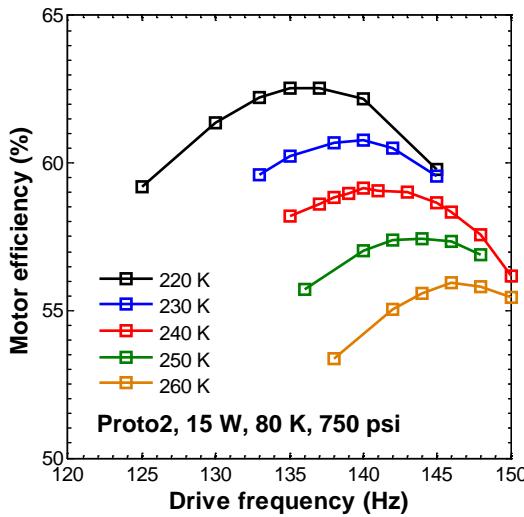
# Performance vs. Fill Pressure

- Input power: 15 W
- Cold tip temperature: 80 K
- Two different expander temperatures and helium fill pressures
- Better performance for higher fill pressure for both expander temperatures
- Effect of fill pressure increased with increasing input powers

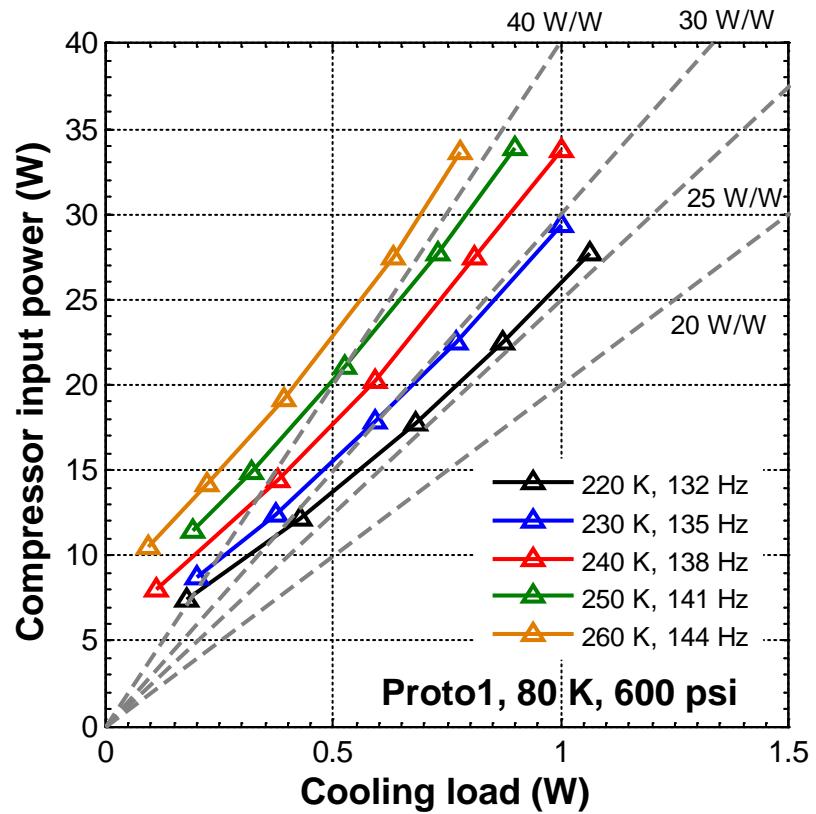
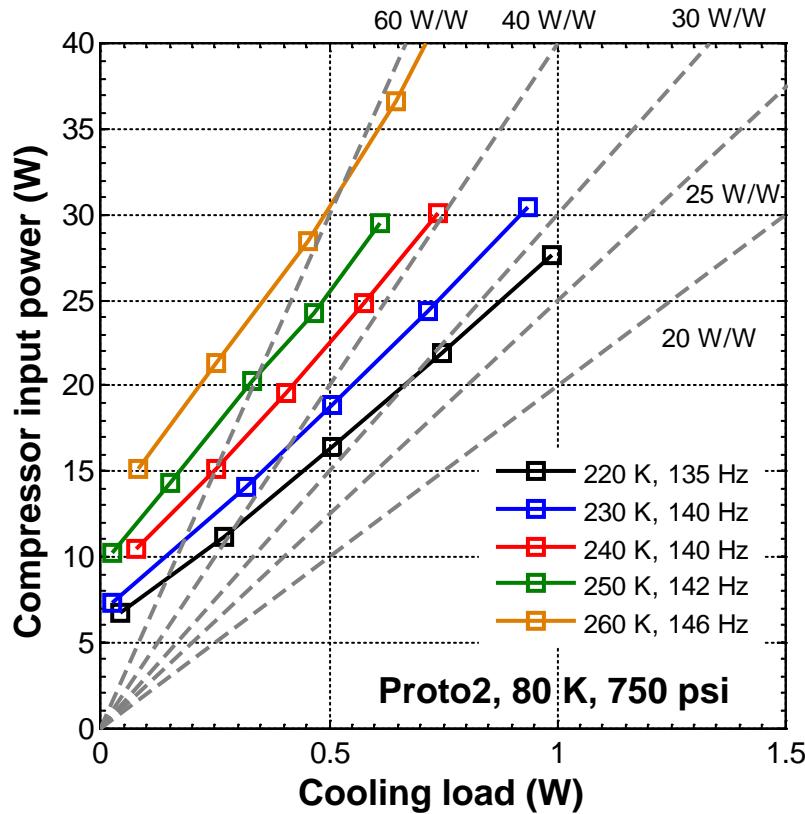


# Unit-to-Unit Comparison

- Input power: 15 W
- Cold tip: 80 K
- Various expander temp
- Optimal frequency decreased with decreasing expander temperature
- Proto1 had better performance
- Proto1 had smaller optimal frequency
  - Lower fill pressure

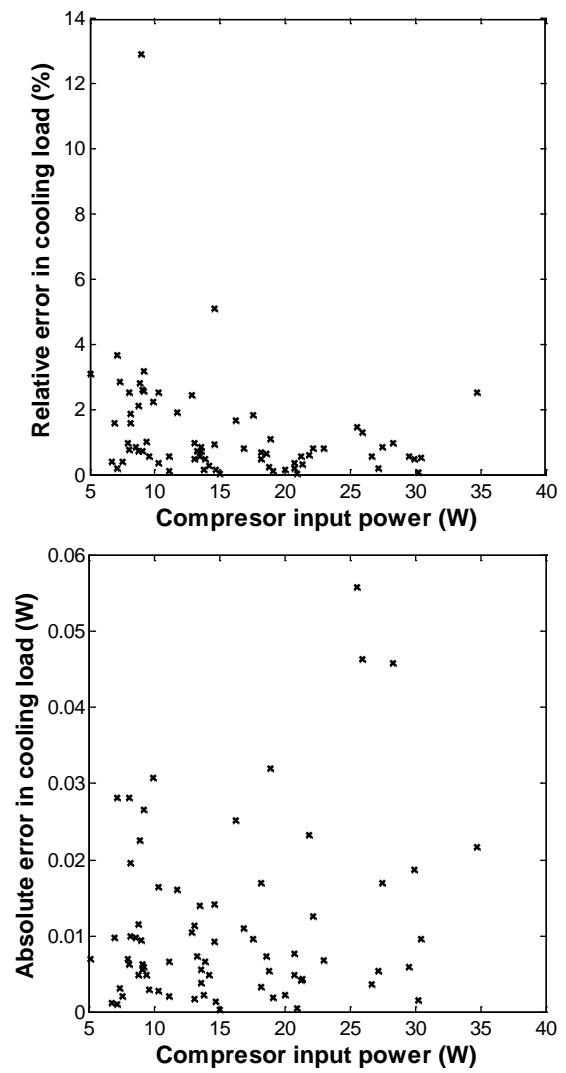
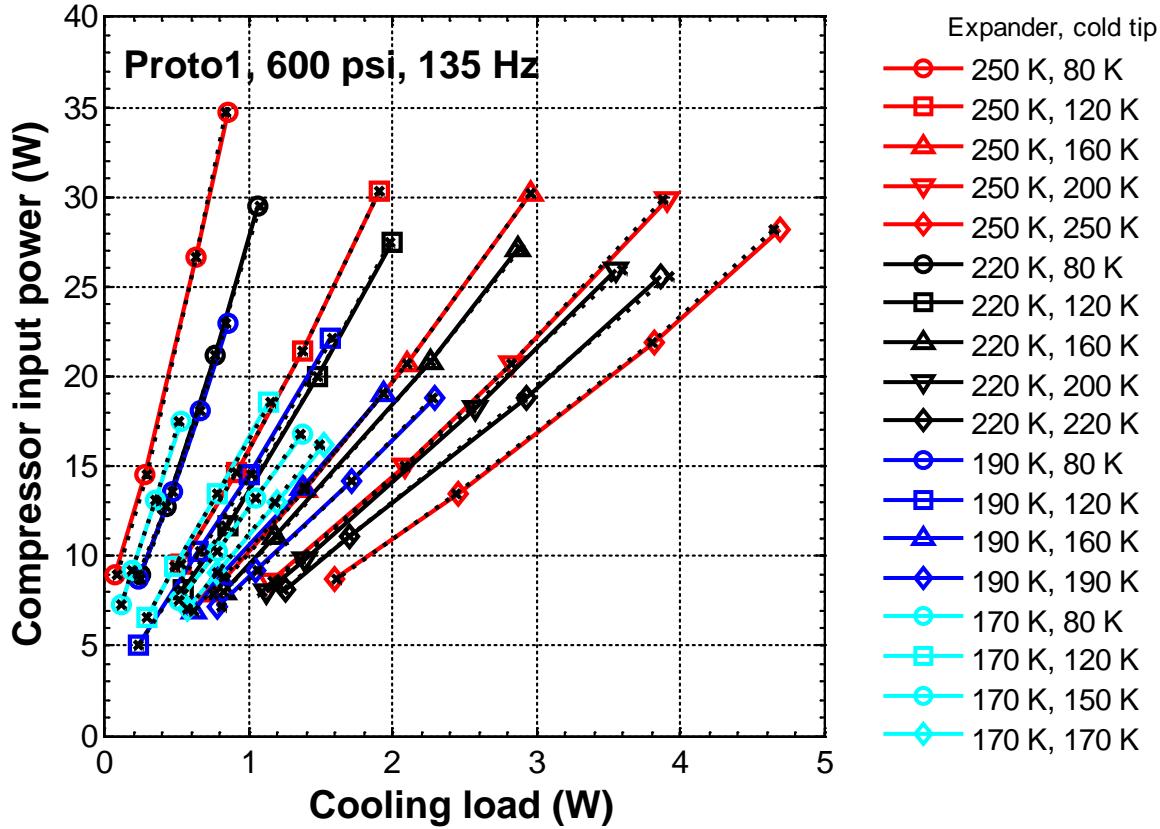


# Performance Comparison



- 80 K isotherms operated at optimal drive frequency
- Proto1 had better performance and less performance degradation with increasing expander temperature

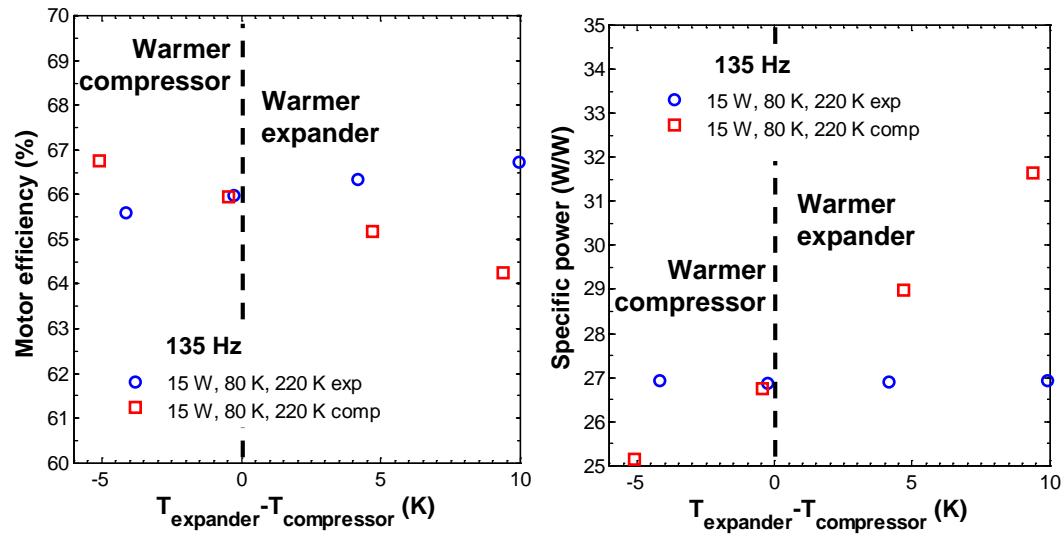
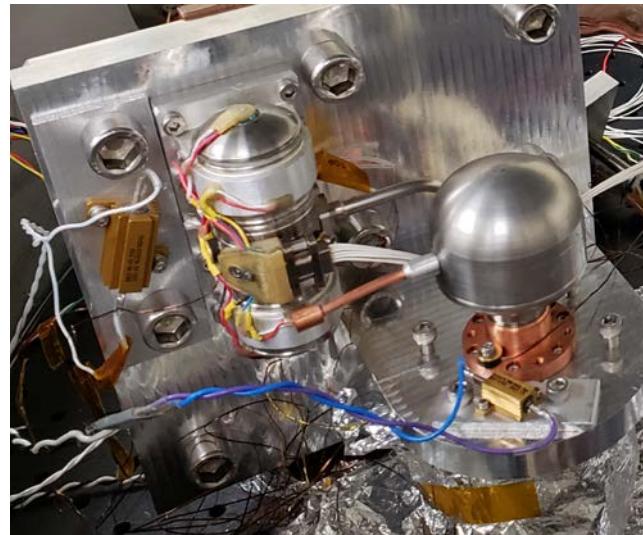
# Performance Fitting



- Proto1, 600 psi, 135 Hz, various expander and cold tip temperatures
- Expression with 27 coefficients:  $Q_{cool}(P_{comp}, T_{CT}, T_{exp}) = AT_{CT}^2 + BT_{CT} + C$
- Represents cooler in transient models to accurately predict cooldown

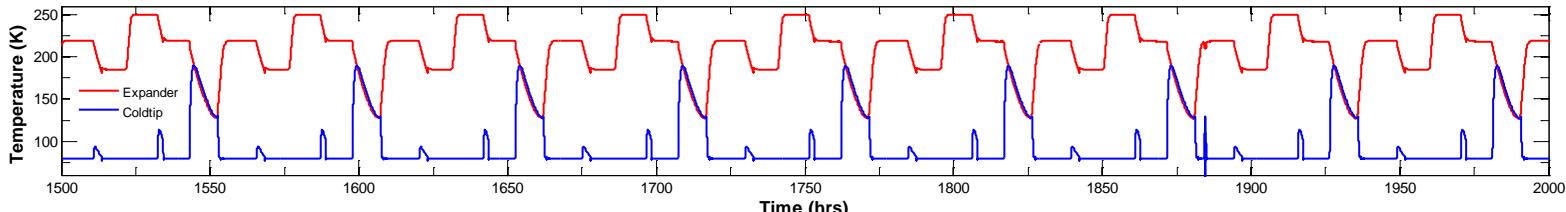
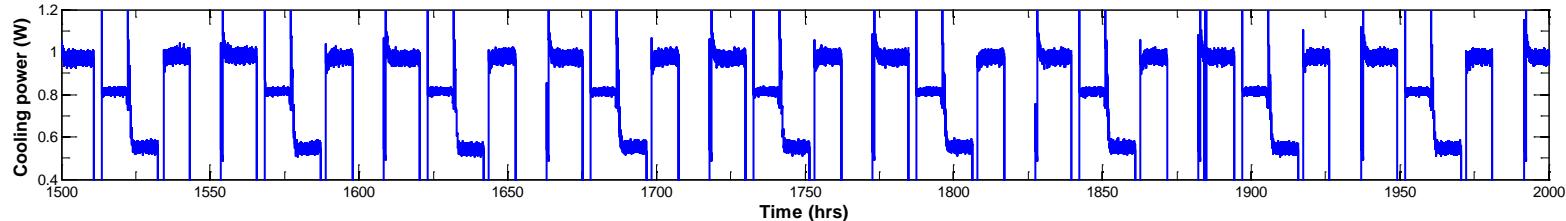
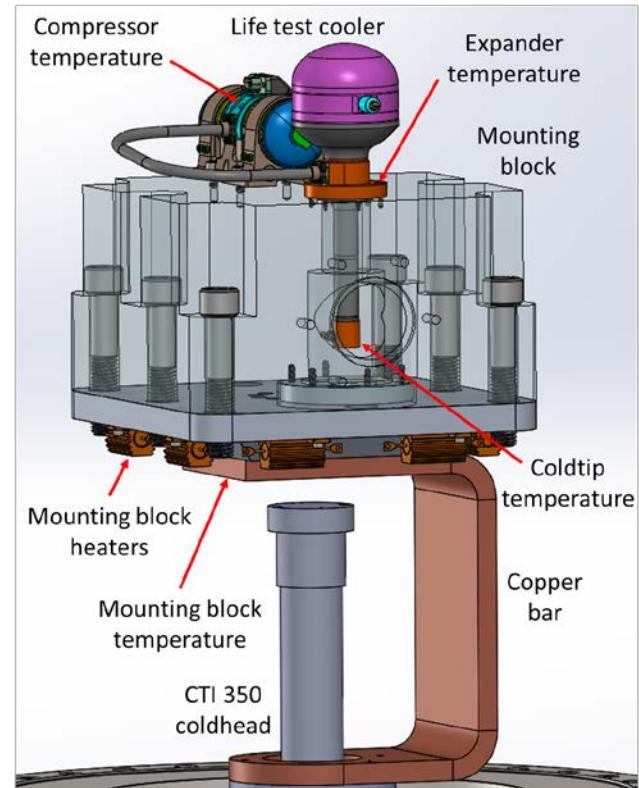
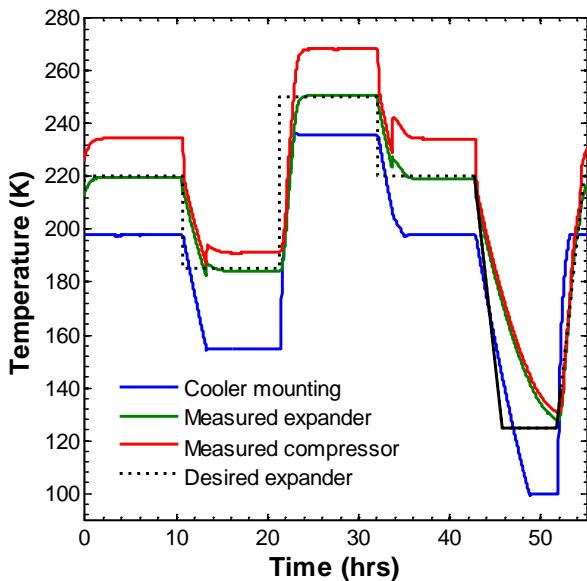
# Effect of Compressor Temperature

- Localized heaters controlled temperature of compressor and expander independently
- Fixed 15 W, 80 K, 135 Hz
- Compressor fixed at 220 K
  - Expander temperature varied
  - Performance increased with decreasing expander temperature
  - Motor efficiency increased with increasing performance
- Expander fixed at 220 K
  - Compressor temperature varied
  - Performance independent of compressor temperature
  - Motor efficiency increased with decreasing compressor temperature

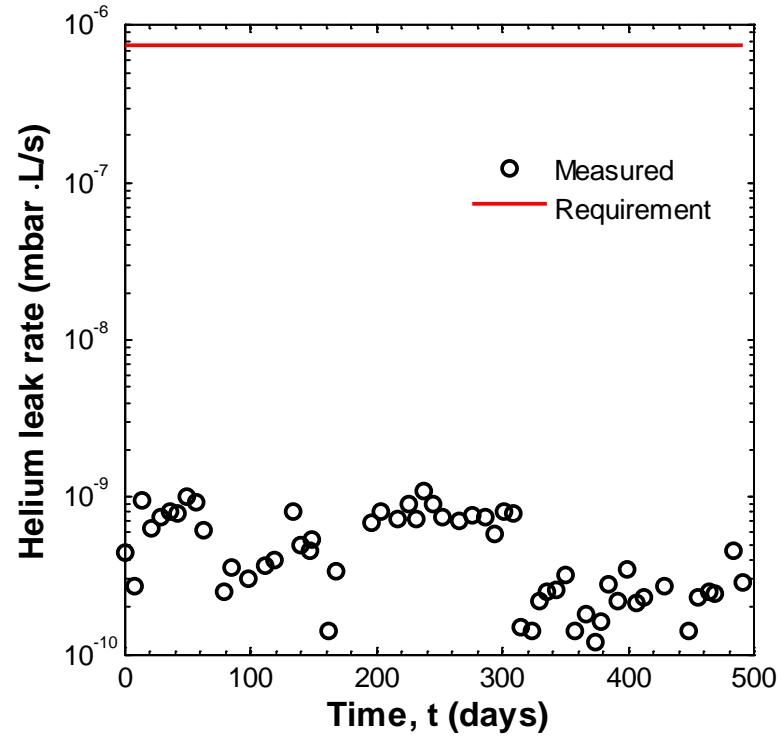
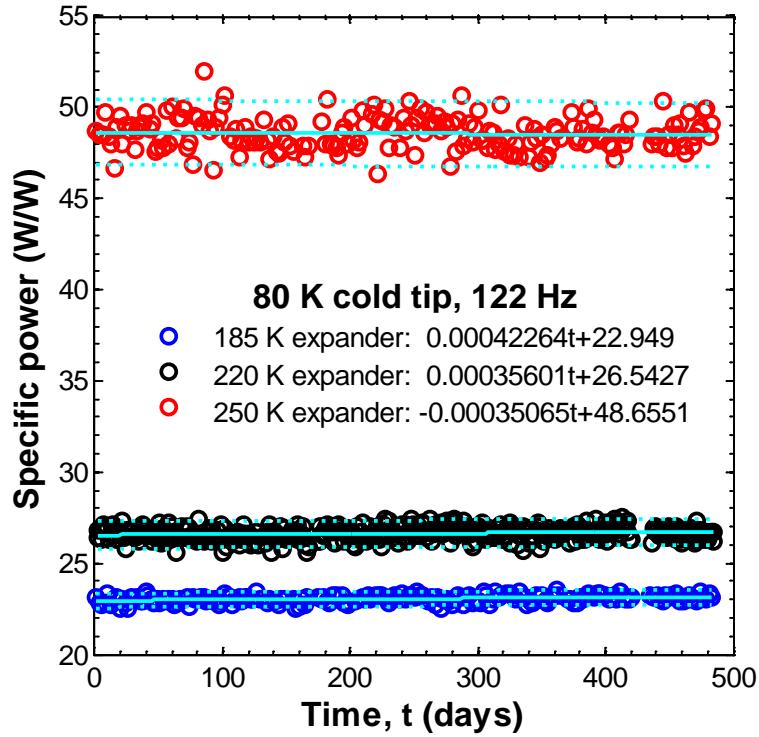


# Life Test

- Op at 220 K for 10 hrs
- Op at 185 K for 10 hrs
- Op at 250 K for 10 hrs
- Op at 220 K for 10 hrs
- Non-op cool to 125 K
- Warm to 140 K, turn on
- Warm to 220 K
- Repeat



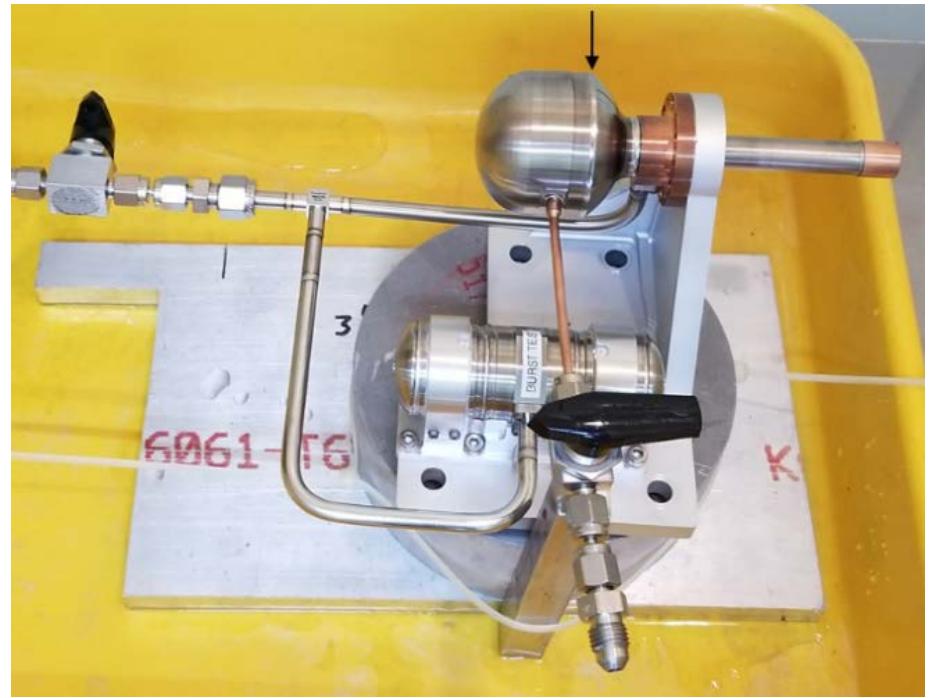
# Life Test Results Analysis



- Specific power changed by less than 1% for all expander temperatures
  - According to linear fit of steady-state performance
- Helium leak rate measured weekly did not change
  - Temperature: 160 K to 250 K
    - No correlation between leak rate and temperature

# Burst Test

- No internal components
- Hydrostatic test
- Burst at 1750 psi in the reservoir volume weld
  - Operating max design pressure (MDP) at 300 K
    - 670 psi in expander
    - 640 psi in compressor
  - Non-op MDP at 323 K
    - 698 psi in both
  - Burst at >2.5x MDP



# Conclusions and Future Work

- Thermal performance of these coolers was measured for various expander temperatures, fill pressures, cold tip temperatures, input powers, and drive frequencies
  - Performance at 135 Hz fit with 27 coefficient polynomial
- Performance was unaffected by compressor temperature up to 10 K colder than expander temperature
- Cooler completed >500 day life test with no performance degradation or increase in helium leak rate
- Cooler passed a burst test by bursting at >2.5x maximum design pressure
- The flight build of this cooler for the MISE Instrument is currently underway

# Thank you for your attention.

## Questions?



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# Extra Slides

# Heat Flow Distribution

- Stainless steel heat flow meters installed on compressor and expander
  - Temperature diode embedded on either side
- Calibrated for various interface temperatures and temperatures across them
  - $Q_{exp} = (0.033T_{IF} + 3.36)\Delta T_{exp} + (-0.046T_{IF} + 2.96)$
  - $Q_{comp} = (0.054T_{IF} + 6.33)\Delta T_{comp} + (0.033T_{IF} - 5.82)$
- Heat flow distribution measured during normal cooler operation
- For all steady-state conditions:
  - Between 54% and 58% of the heat was dissipated at the compressor
  - The compressor temperature was between 4 K and 6 K warmer than the expander temperature



# Performance Fitting Equation

$$Q_{cool}(P_{comp}, T_{CT}, T_{exp}) = AT_{CT}^2 + BT_{CT} + C$$

$$A = DP_{comp}^2 + EP_{comp} + L$$

$$B = FP_{comp}^2 + GP_{comp} + H$$

$$C = IP_{comp}^2 + JP_{comp} + K$$

$$D = C_{01}T_{exp}^2 + C_{02}T_{exp} + C_{03}$$

$$E = C_{04}T_{exp}^2 + C_{05}T_{exp} + C_{06}$$

$$F = C_{07}T_{exp}^2 + C_{08}T_{exp} + C_{09}$$

$$G = C_{10}T_{exp}^2 + C_{11}T_{exp} + C_{12}$$

$$H = C_{13}T_{exp}^2 + C_{14}T_{exp} + C_{15}$$

$$I = C_{16}T_{exp}^2 + C_{17}T_{exp} + C_{18}$$

$$J = C_{19}T_{exp}^2 + C_{20}T_{exp} + C_{21}$$

$$K = C_{22}T_{exp}^2 + C_{23}T_{exp} + C_{24}$$

$$L = C_{25}T_{exp}^2 + C_{26}T_{exp} + C_{27}$$

<b><math>C_{01}</math></b>	<b><math>C_{02}</math></b>	<b><math>C_{03}</math></b>	<b><math>C_{04}</math></b>	<b><math>C_{05}</math></b>	<b><math>C_{06}</math></b>	<b><math>C_{07}</math></b>	<b><math>C_{08}</math></b>	<b><math>C_{09}</math></b>
-1.0821E-10	4.7788E-08	-5.1745E-06	2.6016E-09	-1.1439E-06	1.2187E-04	2.6664E-08	-1.1850E-05	0.001287659
<b><math>C_{10}</math></b>	<b><math>C_{11}</math></b>	<b><math>C_{12}</math></b>	<b><math>C_{13}</math></b>	<b><math>C_{14}</math></b>	<b><math>C_{15}</math></b>	<b><math>C_{16}</math></b>	<b><math>C_{17}</math></b>	<b><math>C_{18}</math></b>
-6.5750E-07	2.9358E-04	-0.030848453	2.7542E-06	-0.001215165	0.130573808	-1.4616E-06	6.5457E-04	-0.071969397
<b><math>C_{19}</math></b>	<b><math>C_{20}</math></b>	<b><math>C_{21}</math></b>	<b><math>C_{22}</math></b>	<b><math>C_{23}</math></b>	<b><math>C_{24}</math></b>	<b><math>C_{25}</math></b>	<b><math>C_{26}</math></b>	<b><math>C_{27}</math></b>
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